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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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LINKING EARTH AND PLANETS

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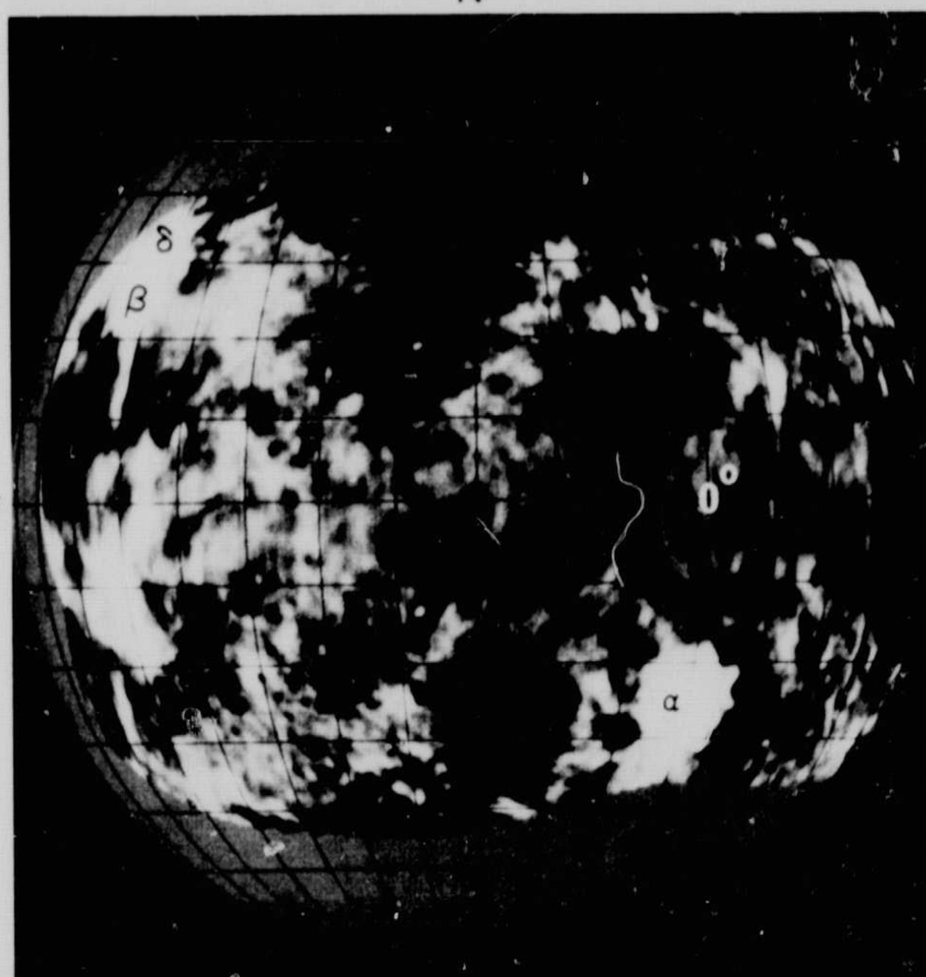
Venus and Mercury as Planets



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EVOLUTION OF THE PLANETARY SYSTEM

Planets of the solar system probably formed four to five billion years ago when hosts of small rocky particles and clouds of gases collected together by their own gravity. Gravity appears to be a universal property of matter, as a result of which every particle, no matter how small, attracts every other. Thus, left to themselves in space, individual particles (and a gas consists of particles: molecules) tend to collect together into large masses.

So after the Sun condensed from the primeval nebula, planets of different sizes and probably different composition originated from concentrations of matter present at various distances from the Sun. And electric and magnetic fields in the gas forced these condensing planets into orbits around the central Sun and spun them on their own axes like tops.

The larger craters on Mars, the Moon, and Venus are thought to be gouged by falling bodies during the final stages of planetary accretion, as the process of falling together is termed. Smaller ones represent a continuing but much lower rate of bombardment by solar system debris.

While Mariner 10, now on its way to Venus, is not designed to find out anything directly about life on Venus, the scientific information about conditions on Venus may be important to biologists seeking understanding of why Earth spawned life and Venus did not. It was life in the primitive atmosphere of Earth which helped to produce the oxygen-rich atmosphere that in turn keeps a lid on the oceans and stops them leaking off into space. Oxygen, converted to ozone at high altitude by the Sun's rays, prevents solar ultraviolet from penetrating low enough into Earth's atmosphere to break water vapor into oxygen and hydrogen. This is important because the hydrogen would bubble off into space like steam from a saucepan and gradually Earth would have lost its oceans in this way.

Cover: The planet Venus as it has been observed from Earth through the technique of radar mapping, in which a radar signal is bounced off the surface of the planet. The three light areas marked with Greek letters (α, β, and δ) are rough sections that may be mountains, but could also be craters or boulder fields. The mapping was done by the Jet Propulsion Laboratory (JPL), using the NASA/JPL deep space antennas at Goldstone, California.

A photographic mosaic of the Earth, taken by Mariner 10, is shown in Figure 1.

THE CHARACTERISTICS OF VENUS

Venus is very similar to Earth in size and mass; its diameter is 7,520 miles compared with Earth's 7,920, its mass and density are slightly less than those of Earth. Physically the two planets are almost twins, but they seem to have grown up quite differently.

Venus, too, is Earth's nearest neighbor in space after the Moon. Its closest approach is 26 million miles compared with 34 million miles for Mars.

But a telescope reveals virtually no details on the bright disc of the planet. Some observers have recorded faint and elusive markings, visible in the near ultraviolet, ill-defined dark shadows and bright patches seemingly behaving very much as cloud systems might behave.

The absence of surface features or persistent cloud features made it difficult to determine the period of rotation of Venus on its axis. Wildly varying estimates were made, ranging from a 24-hour day like that of Earth to a day equal to the Venusian year. The question was not answered until recently when radio waves penetrated the thick clouds of the brilliant planet. Surprisingly, it was found that Venus rotates in 243 days in the opposite direction to that of the Earth. This is slightly longer than the Venus year—the time the planet takes to revolve around the Sun, which is 225 Earth days. Because of the rotation and revolution in opposite directions, the day on Venus is only 127 Earth days. But these figures pose the question of how Venus might have slowed down from rotating as the other planets do and started to rotate in the opposite direction. One of several theories is that Venus captured a large Moon-like body moving in the opposite direction to Venus' spin and that this body crashed onto the surface of Venus. The impact would have stopped Venus from rotating and would also have released tremendous quantities of heat that might have been the cause of extensive volcanism to generate the dense atmosphere of Venus.

Figure 1. A mosaic view of the Earth taken by Mariner 10 on its way to Venus and Mercury. Such pictures were used by the engineers and scientists to test the spacecraft's cameras in space. These pictures were taken when Mariner 10 was 120,000 miles from Earth.

Venus has been the target for several earlier space missions: two successful flybys were made by earlier Mariners, and Soviet Venera spacecraft flew by, orbited, and landed capsules on the surface. These probes confirmed a high surface temperature of around 475°C and a pressure at the base of Venus' atmosphere about equal to that at a depth of 400 fathoms in Earth's oceans. Generally Venus is a hot dry planet with only slight traces of water vapor in its atmosphere of 95 percent carbon dioxide. There are also traces of oxygen, nitrogen, and inert gases, it is believed.

The clouds of Venus, which, according to recent spectroscopic observations, may have a topmost layer of concentrated sulfuric acid droplets, are about 18 to 25 miles thick, and their tops may be about 90 miles above the surface, compared with Earth's highest clouds of six miles or so. Below the Venus clouds is a clear atmosphere, while the clouds themselves probably consist of stacked layers of different composition; for example, carbon dioxide ice at some levels and water ice at others.

Cloud features seen in ultraviolet light appear to move around the planet in only four days. There are also some large scale up-and-down pulsations of the cloud layers.

An interesting theoretical aspect of the dense but clear atmosphere below the clouds of Venus is that if a student could stand on the surface and look around, he would appear to be standing in the bottom of a vast bowl. Looking into the distance in each direction, he would see a blurred, ruddy red landscape curving upwards towards the cloud layers as though he were inside a hollow planet: the atmosphere, acting like a giant lens, would bend the light rays upwards in an effect similar to a mirage appearing on a hot road surface in summer.

This strong bending of light might turn night into a dull day on the night side of the planet, and this could explain the ashen light of Venus. Astronomers have claimed that they see this faint glow on the dark side of the planet when it is turned towards Earth. But this ashen light, first seen in 1643, is nowadays believed to be an auroral glow, like the northern and southern lights over Earth's polar region. Since Venus does not have a strong magnetic field, its auroras can occur all over the planet, whereas on Earth the strong magnetic field causes the aurora-producing particles from the Sun to stream towards the polar regions. One of the spacecraft did observe the glow over the night side of Venus, and the existence of an electrically excited upper atmosphere, the ionosphere, has also been confirmed by spacecraft.

Study of the atmosphere of Venus is important because the whole balance between heat coming in and heat going out from the planet is bound up with atmospheric structure and composition. This heat budget of energy income and spending could explain why Venus is today such a vastly different planet from Earth despite the similarities in size. The great mystery about Venus is how a planet about the same size as Earth, which might have supported oceans in the past as Earth does today, developed so differently during its evolution. Why did the planet lose all its water? Why did the surface temperature rise so high? How did the atmosphere build up such high pressures? How could bodies plunge through this dense atmosphere to produce craters detected by radar?

Answers to these and other questions about Venus will help us understand how planets evolve and why there is an Eden-like Earth while nearby planets are so inhospitable. Understanding how the atmosphere of Venus became, or stayed, inimical to life may help us prevent our own atmosphere from going wrong too, either from natural or man-made causes. An important question today is whether pollution might trigger drastic changes in Earth's atmosphere which could change our planet into another Venus.

At the distance of Venus from the Sun its temperature would be expected to be about 60°C on the average if it were an airless body. Why then is it so much hotter, especially when its clouds reflect a large part of the solar radiation falling upon them? The answer seems to lie in the atmosphere of carbon dioxide. This gas acts, with water vapor, as a one-way transmitter of incoming heat energy from the Sun. It opens a door to let the energy in and slams it shut when the energy tries to go out again. The planet heats up like the inside of an automobile in sunshine with its windows closed.

By contrast, the atmosphere of Earth has only 0.03 percent of carbon dioxide. On Venus, carbon dioxide has remained free in the atmosphere, whereas on Earth in the presence of much water it has reacted with minerals to form large deposits of carbonates. Photosynthesis in plants has also extracted carbon from the atmosphere.

Another mystery about Venus is why it does not have much water. One suggestion is that the water is still entrapped in molten rock beneath a plastic surface which resists fractures. In the formation of Venus, high temperatures drove off carbon dioxide but allowed water to remain in solution in the rocks. As the planet cooled, a plastic crust formed of sufficient thickness to prevent fractures and the consequent escape of water to form oceans.

However, the fact that the planet has not outgassed suggests little differentiation or, at the least, an inactive mantle. If the planet were to outgas, the crust would not be likely to keep the lid on this outgassing.

One theory suggests that water is trapped in voluminous polar caps of Venus; another, that all the water was lost because water vapor could rise in the atmosphere of Venus and be broken down by sunlight into oxygen and hydrogen. The hydrogen boiled off into space. But what happened to the oxygen? It does not appear to be left in the atmosphere.

On the other hand, the major differences among the terrestrial planets may have arisen because these planets formed at different distances from the Sun and thus consisted of different materials in the first instance. For example, Mercury might have formed from materials rich in iron, whereas Venus formed from silicate-rich materials. And Earth may have accreted in a region in which there were water-containing substances while Venus did not. Calculations have shown that the primeval nebula might have separated in this way at various distances from the Sun.

THE CHARACTERISTICS OF MERCURY

Mercury, 3000 miles in diameter, is probably the smallest planet in the solar system (Figure 2). The outermost planet, Pluto, might possibly be smaller. Mercury is halfway between the Moon and Mars in size. Even two satellites of the planet Jupiter are as large as Mercury, though much less dense.

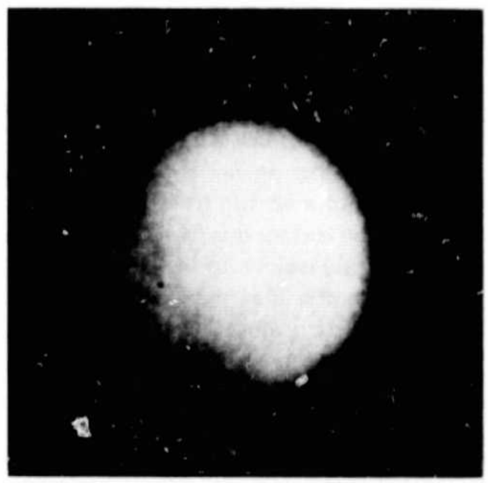

Figure 2. A photograph of Mercury taken at the Pic du Midi observatory in France. This is the best type of picture that can be taken from Earth, but Mariner 10 should send back Mercury photographs as good as the picture of Earth in Figure 1.

At one time it was thought that the closeness of the planet to the Sun caused it to turn one hemisphere eternally sunwards, just as the Moon turns one hemisphere towards Earth. However, radio astronomers discovered very recently (1965) that Mercury rotates on its axis in 58 days. Coupled with the planet's 88-day period of revolution around the Sun, this gives Mercury a solar day of 176 Earth days. So one day of Mercury occupies two years of Mercury time. And because the planet follows an elliptical path around the Sun with its speed in orbit changing as a consequence, the path of the Sun through Mercury's sky is quite erratic. Some parts of Mercury experience a double dawn, for example, in which the Sun rises, then slips back below the horizon, to rise again later.

Through a large telescope the planet presents a yellowish color broken by some grayish patches. Mercury is believed to be cratered and much like Earth's Moon. The grayish areas may be the same as the lunar maria, the great gray plains of the Moon. Mercury, like the Moon, does not appear to have an appreciable atmosphere, and it is a poor reflector of light. But its density is believed to be much more than that of the Moon, possibly a little greater than the Earth's. This is unexplained. It leads to the anomaly that Mercury's surface gravity is greater than that of the bigger planet Mars. A 100-pound student would weigh 40 pounds on Mercury, compared with 38 pounds on Mars and 17 pounds on the Moon. On Venus the same student would weigh 91 pounds.

It is unlikely that Mercury can possess an atmosphere, though some astronomers say they have seen veilings of surface detail at times, in the form of a whitish haze. Despite Mercury's greater surface gravity over that of the Moon, Mercury is closer to the Sun and therefore much hotter than the Moon: molecules can be heated to move at greater velocities and thereby reach escape velocity. Thus, gases that may have come from the rocks as a result of volcanic activity will, over millions of years, have escaped from the planet's gravitational grasp and rocketed as molecules into space.

Mercury does, however, collect plasma from the Sun, the steady stream of particles flung out by the Sun into interplanetary space and referred to as the solar wind. Some of this plasma might indeed form an atmosphere of a kind, as it is temporarily held by Mercury before streaming off again into space.

The surface temperature of Mercury is thought to range from about 325°C at local noon to -125°C at local midnight, but these temperatures vary considerably with the position of Mercury on its orbit as the planet moves in and out from the Sun.

Mercury's surface is exposed to the fierce erosion of the solar wind as well as to solar heat and light. As with Earth's Moon, the solar wind probably changes the composition of the outer surfaces of rocks and surface soils. Solar radiation can vary between five and ten times that received by Earth between aphelion and perihelion of Mercury (most distant and closest parts of its orbit to the Sun). Imagine a day in Earth's desert with ten suns shining at once in the noon sky. That approaches what it may be like on Mercury when the planet is at perihelion.

Key questions about this tiny planet concern its rotation, density, and surface molding. Why does Mercury rotate three times while making two revolutions around the Sun? Might this have produced some unusual surface features? One theory suggests that the heat from the Sun at perihelion may have produced two opposing bulges on the planet which now keep Mercury locked into this peculiar rhythm of rotation and revolution.

Why does Mercury have the highest density among the planets and their satellites? Does it have a central core of iron? And what processes have shaped the surface of the innermost planet?

Mariner 10 is expected to provide much valuable information bearing upon these questions.

STUDENT INVOLVEMENT

Student Project One

From reading astronomical textbooks make four lists as follows:

(1) Those things about Venus that are similar to those on Earth.
(2) Those things that are different.
(3) Those things about Mercury that are similar to those on the Moon.
(4) Those things that are different.

Make a drawing or painting of your impression of the surface of Mercury.

Student Project Two

From the textbooks now make a list of the unknowns about Mercury and Venus, their surface features, their atmosphere, their physical characteristics, their origin, their evolution. Check with a later pamphlet in this series as to what instruments are carried by Mariner 10 and what they might reveal. Identify those present unknowns that might be solved by Mariner 10. Later check the actual results from the flybys and see which of the problems are solved.

Student Project Three

For individual student or as a classroom project. Using the map of the orbits of Earth, Venus, and Mercury prepared as a project in connection with the first pamphlet of this series, mark a position for Earth with a circle on its orbit. Then on the orbits of Venus and Mercury draw circles, approximately to scale (that is, the circle representing Venus should be about the same size as that for Earth and about 2½ times the diameter of Mercury) at the correct positions for eastern and western elongation, superior conjunction (far side of the Sun) and inferior conjunction (between Earth and Sun) and half way between each of these positions, that is, eight positions for each orbit.

Now draw a set of circles showing the relative sizes of each planet as seen from Earth for each of the eight positions. On each of these comparative circles draw the phase of the planet, that is, the part that is in darkness as seen from Earth and the part illuminated; for example, fully illuminated like the full Moon, half illuminated like a quarter Moon, gibbous, and crescent shaped. You will have to calculate the size of the planet at each of these phases from the rule that if the planet is twice as far from the Earth it will appear half as large (in diameter) and so on.

Note how much smaller Mercury always appears to an observer on Earth even when close to the Earth, and how both planets turn their dark hemispheres towards us when they are at the very closest.

Thus you understand why we know so little about these planets and why a spacecraft flying by them can add greatly to man's knowledge of these neighboring worlds.

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